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Data link development for the Archytas vertical takeoff and landing transitional flight unmanned aerial vehicle

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THESIS

DATA LINK DEVELOPMENT FOR THE ARCHYTAS VERTICAL TAKEOFF AND LANDING TRANSITIONAL FLIGHT UNMANNED AERIAL VEHICLE

by

Frederick W. Reichert Jr

June, 1993

Principal Advisor: Michael K. Shields

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This thesis chronicles the development of a data link for the Archytas, a vertical takeoff and landing, transitional flight unmanned aerial vehicle (UAV) prototype being built by the Aeronautics Department at the Naval Postgraduate School. Archytas is intended to be a proof-of-concept platform to satisfy the Navy's real-time, over-the-horizon intelligence mission with a UAV that could be launched and recovered from a small combatant ship. This thesis provides a history of the Archytas command and control data link development, a full description of the data link as delivered for use on the prototype, principles for near term enhancements, and future considerations for the data link should the Archytas concept be adapted for use in an operational combat environment.

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Data Link Development for the Archytas Vertical Takeoff and Landing Transitional Flight Unmanned Aerial Vehicle

by

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Submitted in partial fulfillment
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ABSTRACT

This thesis chronicles the development of a data link for the Archytas, a vertical takeoff and landing, transitional flight unmanned aerial vehicle (UAV) prototype being built by the Aeronautics Department at the Naval Postgraduate School. Archytas is intended to be a proof-of-concept platform to satisfy the Navy's real-time, over-the-horizon intelligence mission with a UAV that could be launched and recovered from a small combatant ship. This thesis provides a history of the Archytas command and control data link development, a full description of the data link as delivered for use on the prototype, principles for near term enhancements, and future considerations for the data link should the Archytas concept be adapted for use in an operational combat environment.

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I. INTRODUCTION

A. PROBLEM STATEMENT

This thesis is part of an ongoing Naval Postgraduate School research project to develop an unmanned air vehicle (UAV) capable of vertical take-offs, vertical landings, and horizontal flight. The current inventory of UAVs lacks a suitable platform able to meet the need for real-time intelligence in fleet operations from small surface combatants. Limited shipboard assets and ship launch-and-recovery capabilities call for systems smaller and more readily deployable than the current systems. A candidate for the vertical take-off and landing (VTOL) mission must not only takeoff and land vertically, but transition to horizontal flight for a high dash speed and efficient loiter capability to conduct operations once on station. (Howard, 1992)

B. THESIS SCOPE

This thesis documents the specification and procurement of a telemetry package developed to satisfy the requirements for a computer-to-computer data link for a specific phase in the evolutionary development of the Archytas VTOL transitional flight UAV project. This thesis is intended to provide designers and developers of the Archytas prototype with a record of how the data link between the UAV and the ground

control station was developed and implemented so that researchers will not have to repeat a search through alternatives already examined. This document also provides data link reconfiguration options and implementation considerations to future Archytas project participants. Chapter II provides an overview of the Archytas project and the evolutionary Archytas avionics development being employed at the time of this writing. Chapter III describes the functional requirements for the Archytas data link, the constraints which limited the spectrum of solutions, and proposes a system which meets these requirements. Chapter IV reports the results of tests conducted to determine how well the acquired data link hardware met the requirements developed in Chapter III. A detailed description of the data link as implemented on the Archytas is also provided. Chapter V proposes methods for improving data link's capabilities and methods to capitalize on the data link's flexibility to meet changes in requirements. Chapter VI is a projection of data link requirements should the Archytas concept be accepted by the Department of Defense and considered for acquisition. Requirements discussed include interoperability in a joint environment, data link robustness, communications security, and multiple mission operation.

A packet radio data link was chosen for the prototype Archytas since it was the best available solution that was within budgetary constraints. Initial tests of the data link

indicate that it will satisfy the original requirements and have enough flexibility for improvement and expansion to satisfy follow on phases of the project. The procured data link is not capable of performing in a combat operational environment but the link for the prototype Archytas does serve as a base model from which many operational design characteristics can be garnered.

II. ARCHYTAS AVIONICS

This chapter provides an overview of the Archytas project and a summary of the evolutionary approach to the development of the Archytas command and control structure.

A. ARCHYTAS OVERVIEW

The Aeronautics Department of the Naval Postgraduate School is currently developing a prototype platform as a proof-of-concept for a Vertical Take-Off and Landing (VTOL) Unmanned Aerial Vehicle (UAV) which can transition to horizontal flight. The platform, called the Archytas (pronounced are-KEE-tas), is a hybrid of two cancelled programs: The AROD ducted-fan VTOL, and the AQUILA horizontal flight UAV. Fundamentally, the Archytas is a ducted-fan AROD hovering air vehicle with Aquila wings.

1. AROD

The Airborne Remotely Operated Device (AROD) is a gasoline-powered fan within a duct which provides vertical hovering flight by directing air in a downward thrust greater than weight of the vehicle. Anti-torque and maneuver controls are provided by four remotely controlled fins in the air flow path at the bottom of the vehicle. Surplus AROD platforms are being used as the primary structure for Archytas. The AROD is well suited for UAV missions requiring the platform to take

off and land on its own power, in a limited amount of space, and without the aid of external devices such as a launcher or recovery net. The major deficiency of the AROD platform is its inability to loiter for long periods of time or obtain a high dash velocity characteristic of fixed-wing, horizontal flight UAVs, such as the Aquila.

2. AQUILA

The Aquila is the product of an Army program that was intended to provide fixed-wing, horizontal flight, rail-launched, net-recovered UAVs to the battlefield commander for real-time over-the-hill and over-the-horizon intelligence of enemy disposition. After many years of development, the Army program was never funded by Congress for full rate production and was cancelled. During development, many prototype Aquila vehicles were produced and tested. One of the major failings of Aquila is its inability to be consistently recovered in a capture net without snapping the wings from the aircraft due to the stress of the sudden stop. (GAO, 1987) The surplus Aquila wings, being lightweight and manufactured of a durable composite Kevlar material, are very suitable for the Archytas project. Since the Archytas will be recovered by vertically landing on its own power at a low rate of decent, the wing-to-fuselage stress is considered negligible for the Archytas compared to the Aquila.

B. ARCHYTAS AVIONICS EVOLUTIONARY APPROACH

The avionics for Archytas includes all the hardware and software required to maintain man-in-the-loop command and control of the UAV with the ability to assess the vehicle attitude, velocity, acceleration, and location in three dimensions in real time. This definition allows for autonomous flight provided that the UAV can be rerouted or reprogrammed in flight at the will of a remote pilot. The man-in-the-loop is intended to be a fall-back safety requirement to maintain control of the vehicle should the autonomous internal control fail. The avionics package also includes all on-board communications, payload controls and products, sensors, computers and other electrical and electro-mechanical devices and linkages required to sustain flight, perform the intended mission and recover the UAV. Archytas avionics are being developed in five evolutionary phases, each phase adding more capability, and hence complexity, to both the UAV and ground control station electronics, processing and instrumentation packages.

1. Phase 1: Remote Control

The first avionics iteration is nearly identical to a typical model airplane control. The command link is a hand-held model airplane control transmitter and on-board command receiver available from any hobby shop. Radio frequency (RF) modules have been replaced so the control link operates on a

military frequency. A command on the control transmitter, such as a change in switch position or a joystick movement, is encoded with pulse width modulation, time-division multiplexed with other command inputs, then transmitted to the UAV using frequency modulation. The signal is received, demultiplexed, and the commands routed to the appropriate servo. The signals bound for the servos are not decoded since the servos require a pulse width modulated baseband signal to operate. This is an analog, real-time system. A block diagram of the avionics for this phase is shown in Figure 1. Flight of the UAV is controlled by a pilot on the ground.

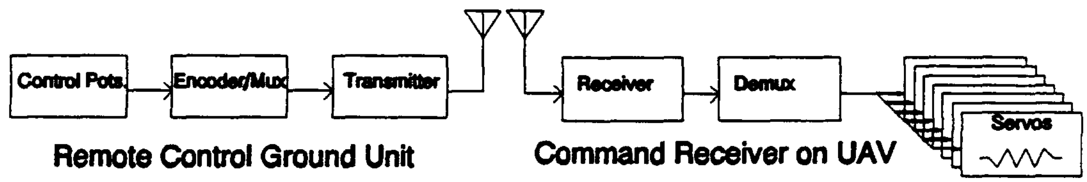

Figure 1 Phase 1: Remote Control

2. Phase 2: Direct Link Feedback

The second phase is ground based and intended to test and measure servo feedback monitoring parameters using a personal computer as the measuring instrument. The remote control built in Phase 1 provides on-the-air stimulus to the servos. A separate circuit on the servos provide a feedback to indicate the position of the servo. An analog-to-digital circuit converts the analog voltage from the servo position sensors to a discrete digital value as input to the personal

computer. Sensors, such as a wind speed indicator or axis indicator, are added to the avionics package in this phase and are connected to the computer in the same fashion as the servo position sensors. A block diagram of the avionics for this phase and the link to the computer are shown in Figure 2.

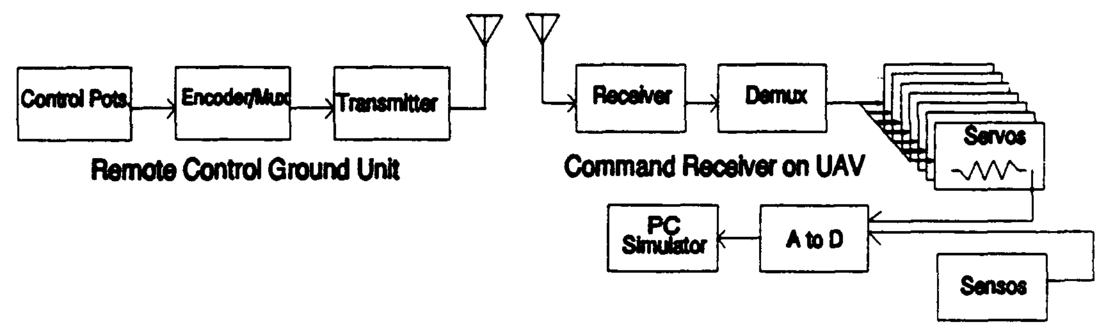

Figure 2 Phase 2: Direct Link to the Ground Computer

3. Phase 3: RF Data Link

Phase three introduces an on-board central processing unit (OB CPU) such as an Intel 486 to act as the interface between the sensors and radio link. An on-board computer is the first step toward distributed processing and semi-autonomous flight control. At this phase, a human pilot on the ground maintains positive flight control through the command and control uplink. Analog sensor data is converted to discrete digital values and collected by the OB CPU. Sensor data is relayed via radio frequency computer-to-computer link to the ground station personal computer for flight analysis. A block diagram of the avionics for this phase are shown in Figure 3.

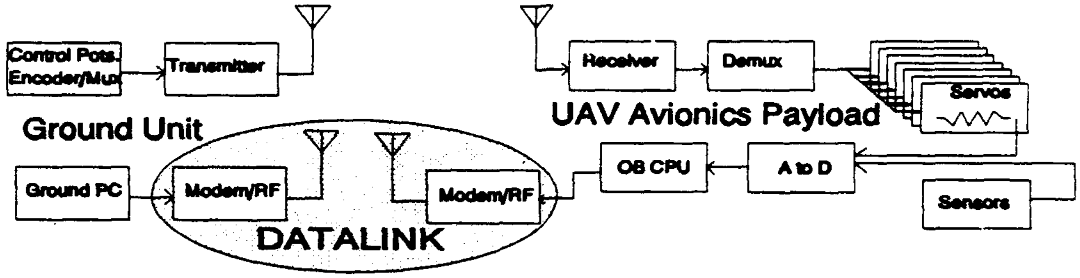

Figure 3 Phase 3: Computer-to-computer Link

4. Phase 4: On-Board Navigation

Phase four builds onto the semi-autonomous flight architecture by adding several navigation aids. These aids include an inertial navigation system that provides three dimensional acceleration vectors, a Global Positioning System (GPS) receiver, and a variety of non inertial sensors that measure altitude based on barometric pressure, airspeed, angle of attack (α), and angle of slip (β). A software algorithm in the OB CPU uses an external time base, the on-board GPS receiver, and the non-inertial sensors to calculate the position, velocity and acceleration of the UAV while in flight in real time. Phase four will also introduce Differential GPS, precise location calculations based on the readings from the GPS receiver on the UAV and another co-located with the ground station. Differential GPS enables the ground station to precisely locate the UAV within two meter positional accuracy. Additionally, the ground computer can perform as a flight data recorder and store data passed to it from the OB

CPU through the RF data link that was introduced in Phase 3. Every aspect of the flight can then be replayed and analyzed. A block diagram of the components of this phase are depicted in Figure 4.

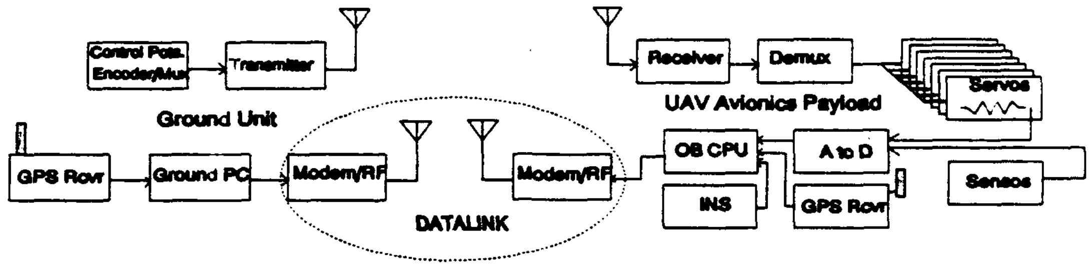

Figure 4 Phase 4: Navigation Instrument Support

5. Phase 5: Weaning Toward Computer Control

Phase five provides for joystick direct control by the remote pilot for take-offs, landings, and anticipated trouble times such as aircraft transition from horizontal to vertical flight. Such complex moves, better left to pilot intuition, cannot be modeled until this phase is completed. During the rest of the flight, the computer-to-computer data link will provide the method and path for controlling the UAV. Distributed processing concepts are used to keep the data exchange between the two computers to the essential minimum in order to remain within the bandwidth capabilities of the RF Data Link. At this point the command and control of the UAV flight is conveyed from the ground computer through the RF data link developed in Phase 3 and the uplink developed in

Phase 1 is for back-up only. Figure 5 displays the dual connection of the pilot control path through both the computer-to-computer RF data link and the back-up command link. A signal switch on the UAV provides for remote selection between the primary data link and the back-up command link. When the primary link is selected, the OB CPU sends servo data to the pulse generator which converts the digital commands from the OB CPU to pulse width modulation (PWM) as required by the servos.

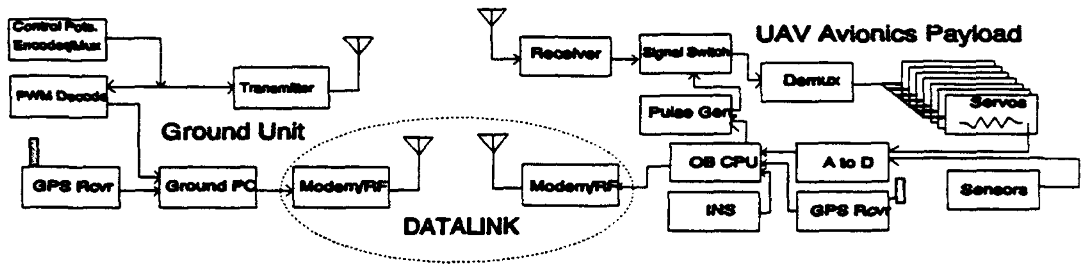

Figure 5 Phase 5: Computer Controlled Flight

6. Beyond Phase 5

Future iterations of the Archytas architecture will most likely include harnessing higher computer processing power for the OB CPU for autonomous flight control during the conduct of missions, and more efficient methods of distributed processing for better vehicle and payload control.

This thesis is concerned with the primary data link introduced in phase three. The data link is intended to provide a transparent computer-to-computer communications path

between the processor on board the UAV and the processor located at the ground control station. Transparency of the data link will allow the computers to communicate as if they were directly connected by cable.

III. DATA LINK DEVELOPMENT

This chapter describes the functional requirements for the Archytas data link, the constraints which limited the spectrum of solutions, and the proposed solution.

A. ARCHYTAS DATA LINK PROBLEM STATEMENT

Phase 3 objectives of the Archytas Unmanned Aerial Vehicle (UAV) project require, in part, a computer-to-computer communications channel, which shall be referred to as the Archytas primary data link. The evolutionary approach to Archytas avionics development requires the Phase 3 data link decision to satisfy follow-on phases of the project as well. The data link is an operational requirement for successful operation and testing of the Archytas proof-of-concept prototype. The data link developed for the prototype is not intended for as-is incorporation into the development of a production version should the Archytas be accepted for acquisition and integration into the present force structure. Certainly, many considerations for the Archytas prototype data link will apply to a production version. These considerations will be addressed in Chapter VI. The data link solution for the Archytas prototype will be based solely on the requirements and limitations criteria for the prototype.

B. DATA LINK DEVELOPMENT CRITERIA

Criteria considered in the development of the Archytas data link are listed in Figure 6. The list is the product of several Archytas project meetings in which desirable features and limitations of the required data link were discussed. The list contains only those criteria considered the minimum essential data link requirements for selection of appropriate commercial off-the-shelf (COTS) equipment able to satisfy requirements. Criteria are not listed in order of merit. Some criteria cannot be judged without accounting for its impact on other criteria. Synergism between criteria must be taken into account.

- **medium**
- **power**
- **speed**
- **interfaces**
- **modularity**
- **data flow**
- **size**
- **commercial availability**
- **frequency agility**
- **hardware adaptability**
- **software flexibility**
- **technology hardness**
- **weight**
- **cost**

Figure 6 Data Link Development Criteria

1. Medium

One computer will be on board the Archytas UAV and the other will be on the ground. The Archytas is intended to achieve untethered flight. The data link must therefore be wireless and capable of supporting communications up to 35 miles line-of-sight without a relay or repeater station.

Applicable wireless communications media are light and radio frequencies.

2. Power Consumption

The data link must be as electrically efficient as possible. Power consumption impacts on weight limitations. Since the power source is an alternator driven by the Archytas engine, any current drawn by the data link will result in less horsepower available for lift of the aircraft. Total allotment for the data link is 48 ounces (3 pounds). This allotment includes the total weight of the on-board hardware package and the cost of lost thrust due to some of the engine's horsepower being used to create electricity. To estimate the weight impact due to power consumption, worst case approximations are used in the series of equations below to determine the current to weight ratio. Archytas lift, which is equal to its thrust in the vertical flight mode, is approximately one hundred pounds. The horsepower rating is twenty-two electrical horsepower.

$$\frac{LIFT}{ElectricalHorsepower} = \frac{lbs}{E.H.P.} = \frac{100}{22} = 4.55\frac{lbs}{E.H.P.} \qquad \textbf{Eq(1)}$$

Noting the conversion of horsepower to volt-amps,

$$1\ E.H.P. = 746\ watts\ (volt\text{-}amps) \qquad \textbf{Eq(2)}$$

the measured available potential,

$$Alternator\ Output = 55\ volts \qquad \textbf{Eq(3)}$$

and assuming that the alternator is reasonably efficient,

$$Alternator\ Efficiency = 60\% \qquad \textbf{Eq(4)}$$

we obtain a ratio of available power to horsepower.

$$\frac{746\ VA}{E.H.P.}\ x\ 60\%\ Alternator Efficiency = \frac{448 Available VA}{E.H.P.} \qquad \textbf{Eq(5)}$$

Using the results of Equation 1 and Equation 5, a ratio of power to lift is obtained.

$$\frac{Available VA per E.H.P.}{Pounds Lift per E.H.P.} = \frac{448}{4.55} = 98.46\ VA per Pounds of Lift \qquad \textbf{Eq(6)}$$

Applying the known alternator output voltage from Equation 3 results in the ratio of current to lift.

$$\frac{VA per Pounds of Lift}{Alternator Output} = \frac{98.46}{55} = 1.79\ Amps per Pounds of Lift \qquad \textbf{Eq(7)}$$

The reciprocal of Equation 7 provides the worst case estimate that every ampere of current drawn by the data link equates to 0.56 pounds of weight that must be applied to the total data link weight as indicated in Equation 8.

$$1 Amp = .56\ Pounds of Lift \qquad \textbf{Eq(8)}$$

3. Speed

Required speed refers to the desired throughput of UAV related data, in two directions, between the ground control station computer and the computer on the UAV **and** the data link overhead. Overhead consists of the throughput required to

manage the link and ensure accurate data transmission. Manufacturers of data link devices generally do not discount data link management overhead in their claims of throughput. The estimated total throughput which satisfies the Archytas Phase 3 and Phase 4 requirements is 14,812 bits per second. Calculations of the estimate are shown in Figure 7 and are based on the amount of control data to be sent up, surface indications and instrument readings to be sent down, and estimated data link management overhead.

4. Interfaces

To minimize the need for adaptation or translation between the data link device and the computer, standard interfaces at the physical and data link layers are desired. Therefore, the data link should accept the same physical and electrical characteristics found on most personal computers, such as an RS-232 serial port using either a DB-25 or DB-9 receptacle, or a parallel port using a Centronics connector. This standard for connecting an external communications device to the computers is assumed to provide the greatest flexibility and support both for interconnection hardware and communication device driver software.

5. Modularity

The data link solution should be modular in hardware design. A good modular design will ease fault isolation and replacement or repair of faulty parts, and allow for ease in

Controls to be Uplinked

Device	Qty	Refresh Rate	Bits per Update	bps
Controls				
Throttle	1	20 Hz	8	160
Control Vanes	4	40 Hz	8	1280
Wing Aerilons	2	40 Hz	8	640
Canard Aerilons	2	40 Hz	8	640
				2720

Servo Positions to be Downlinked

Device	Qty	Refresh Rate	Bits per Update	bps
Controls				
Throttle	1	20 Hz	8	160
Control Vanes	4	40 Hz	8	1280
Wing Aerilons	2	40 Hz	8	640
Canard Aerilons	2	40 Hz	8	640
				2720

Auxiliary Equipment Data to be Downlinked

Device	Qty	Refresh Rate	Bits per Refresh	bps
Controls				
GPS	1	1 Hz	2400	2400
INS	1	50 Hz	24	1200
				3600

Total Data Link Throughput Requirement

Device	bps
Controls	2720
Servo Positions	2720
Instruments	3840
Auxiliary Equipment	3600
Estimated Data Link Management (15%)	1932

Total Data Link Throughput 14812 bps

Figure 7 Total Data Link Throughput Requirement Estimate

modification and upgrading should the need arise.

6. Data Flow

The data link is a point-to-point communications link. The prototype is not intended to fly beyond line-of-sight. For this reason, no data link that requires a relay or intermediary within a forty mile radius will be considered.

7. Size

Space aboard the Archytas is extremely limited. The data link hardware must be placed in one of two locations; inside an electronics pod, or strapped to the outside of the Archytas duct. Each place has its advantages and disadvantages. The electronics pod is an aluminum enclosure physically separated from the engine and the electromagnetic interference (EMI) it may produce. The pod protects its contents from both the elements and, to a small degree, from EMI. Co-location of the data link hardware with the on-board computer would minimize cabling weight and data transfer distance. The disadvantage of the pod is the limited space and configuration requirement. Available space in the pod for the data link consists of one, possibly two circuit card slots, seven by four inches each. A majority of the Archytas avionics is planned to be housed in the pod, including the on-board computer, another source of EMI. If the pod houses the command uplink receiver, the on-board computer, and the data link transceiver there would be three devices, sitting side-

by-side, creating and using radio frequencies. Full isolation of the devices from one another in such a limited space would be a major electrical engineering task. The outside of the duct affords flexibility for variations in packaging which do not fit within the circuit card rack in the pod, but the location is unshielded from the atmospheric elements and still has some dimensional restrictions. The duct has side panels between its eight struts. The mounting area between the struts is nine inches square. Flexible packages which can follow the outside curvature of the duct can be two and one half inches thick and remain within the profile of the duct shroud. Due to the curve of the duct, rigid packages can be no thicker than one and one half inches. One other disadvantage of mounting data link hardware on the exterior of the duct is increased weight of the cables that would be needed to interconnect the data link to the on-board computer, the radiating device (such as an antenna) and the power distribution strip.

8. Commercial Availability

The solution is intended to be a commercial off-the-shelf (COTS) product which is immediately available to meet the limited time schedule of the project.

9. Frequency Agility

Frequency agility refers to the user ability to select the frequency assignment of the emitting device, be it a radio

or light transceiver. The requirement allows the Archytas project participants to relocate the data link to the best frequency possible should interference from a source external to the UAV be encountered. The data link transceiver should be able to operate within frequency bands allocated to Navy use under the provisions of Naval Telecommunications Publication (NTP-6). Another consideration for frequency selection is the impact on antenna size and free space path loss. The lower the frequency, the longer the antenna must be electrically to radiate efficiently and provide the correct balance in standing wave ratio to the transmitter. Although an antenna can be physically shortened and maintain its electrical length, its gain and radiation characteristics are diminished. As shown in Figure 8, the higher the frequency, the shorter the wavelength, and the higher the free space path loss per mile. Excessive path loss would have to be made up in the form of amplification, which costs weight and power, or in higher gain directional antennas, which requires a steering mechanism which also draws power, adds weight, and makes the project more complex. Frequency agility allows the Archytas project participants to obtain the optimum frequency solution for the current phase of the project.

10. Hardware Adaptability

Standard interfaces support a modular approach and so too should the design of the data link hardware. Where

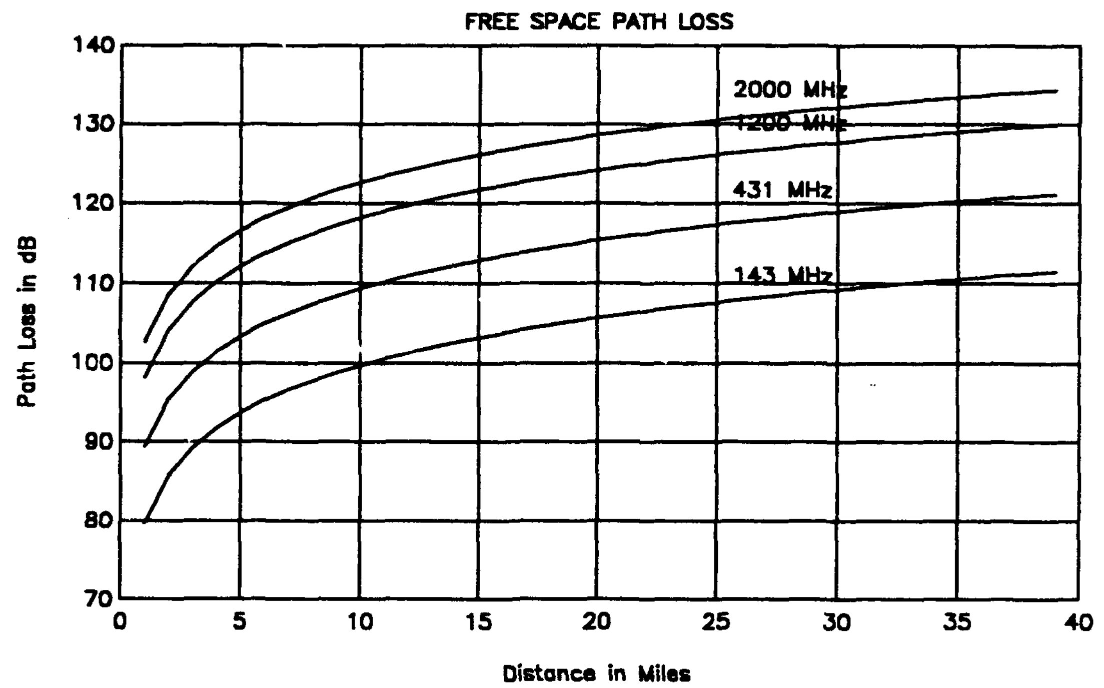

Figure 8 Free space path loss curves

modularity allows for replacement of faulty parts, hardware adaptability allows for changes in project design or change of project scope. Since the Archytas is a prototype, modular components will allow quick reconfiguration should Archytas avionics require a change in the overall working solution. To this end, the data link should be able to adapt easily to unforseen changes in design.

11. Software Flexibility

Realizing that control of the data link must be done internally and not by the computers to be linked, the data link solution will most likely require an algorithm to control itself. Whether the algorithm is in software, firmware, or a

combination, the algorithm must allow for modification by Archytas participants for adaptation of the link to specific requirements in accordance with project phase.

12. Technology Hardness

The Archytas project is not a test of data link but of the Archytas concept. The data link must therefore employ a proven, well documented and supported technology.

13. Weight

As stated earlier, the total weight limit for the data link is three pounds. This weight includes the dry weight of the equipment, cabling, antenna, and loss of lift due to power consumption.

14. Cost

The budget for the data link is $2000.

C. SOLUTIONS CONSIDERED

This section plays out the scenario without cost as a criteria. This has been done intentionally to provide future Archytas participants with a slate of possible data link solutions should funding become less restrictive.

1. Commercial UAV Telemetry

There is a growing commercial market of telemetry products for UAV applications. A partial list of telemetry device manufacturers is in Appendix A. Telemetry products are relatively small, lightweight, capable of 100% duty cycle, and are uni-directional links. To provide a UAV with a bi-

directional link, either half or full duplex, requires a transmitter-receiver pair both on the UAV and at the ground control station. They are small, lightweight, fixed frequency or frequency agile, operate in the UHF or microwave bands, and are capable of data rates much greater than 64 Kilobits per second. Similarly, they are manufactured to withstand the environmental severity of UAV flight such as vibration, shock, acceleration, humidity and altitude. If it were not for the prohibitive price, (around $10,000 for a TTL compatible, bi-directional telemetry link) commercial UAV telemetry equipment would be the product of choice for the Archytas project.

2. Ethernet Local Area Network

A more fiscally friendly approach investigated was the adaptation of the inexpensive ethernet architecture for point-to-point use. An ethernet uses a common light, base band, or radio frequency to network two or more computers together. The computers are connected to the network using an ethernet circuit card. The card is inserted into a slot on a computer back plane or is connected to the computer externally through one of the computer serial or parallel ports. The network card connects to other computers on the network via light or radio. A diagram of a typical ethernet configuration as it would apply to the Archytas is shown in Figure 9. Only one computer can transmit data at a time since ethernet time-shares the interconnecting medium using carrier sense multiple

access with collision detection (CSMA/CD) medium access control technique. A computer wishing to transmit first senses the medium and transmits only if the medium is idle. (Stallings, 1991, p. 348) Several manufacturers make wireless ethernet cards. Generally, infra-red light is used in open areas where there is line-of-sight with the other computers and the computers are within a 250 foot radius of each other. Wireless radio frequency ethernets boast up to a 2 Megabit per second data rate and operate using spread spectrum between 902-928 Mhz. This is an industry standard frequency which requires no prior Federal Communications Commission approval or license. Power is restricted to less than one watt output which greatly restricts the communication distance. Compensation for path loss would be the major obstacle for this solution. The free space path loss would range from 96 to 128 dB at the 35 mile maximum operating range of the UAV based on Equation 9.

$$Path\ Loss_{dB} = 36.58 + 20\log Dist_{Miles} + 20\log Freq_{Mhz} \qquad \textbf{Eq(9)}$$

Such a loss would require that gain be made up elsewhere, such as amplification and antenna gain which adds weight, increases power consumption, and requires larger directional antennas. Beyond the gain problem is the shared use of the 902-928 Mhz spectrum. The higher the UAV flies, the greater the radius to its radio horizon. Equation 10 shows the relationship of height to horizon.

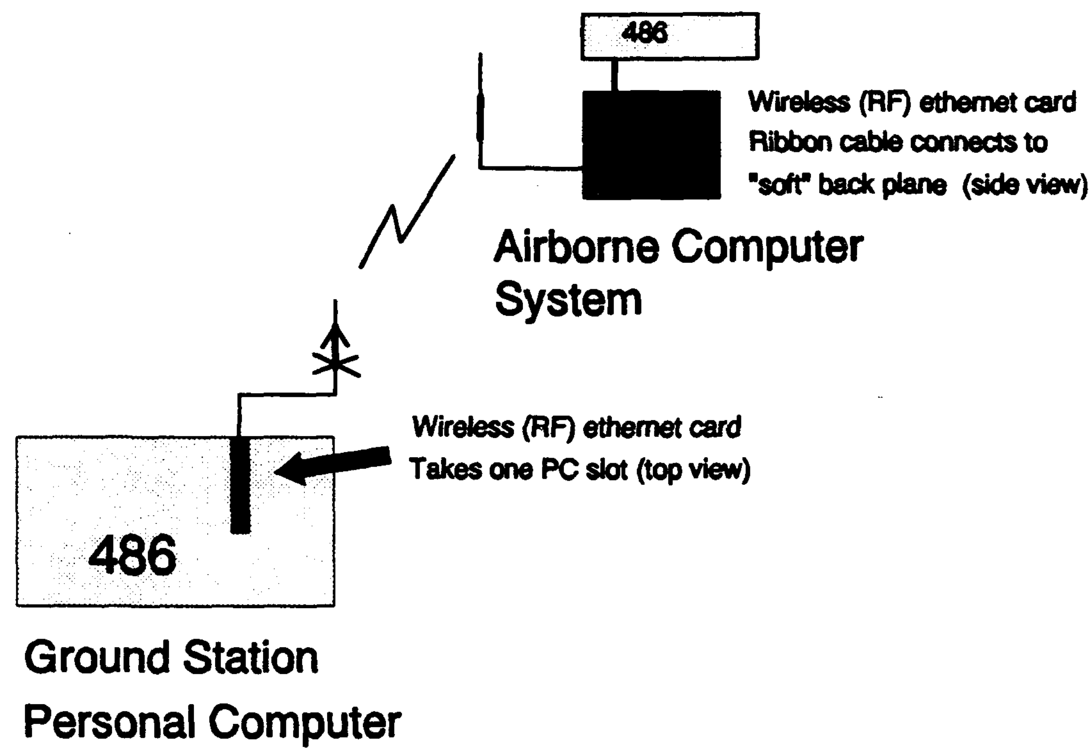

Figure 9 Typical wireless ethernet configuration

$$Distance\,to\,Horizon_{Miles} = \sqrt{2 \cdot Height_{Feet}} \qquad \text{Eq(10)}$$

Wireless ethernet cards are designed for a single, common frequency. Without some sort of frequency agility, the data link must compete for the frequency. The higher the UAV flies, the greater the chance it will become within line-of-sight of other users of the ethernet. Until future versions of wireless ethernet cards become frequency agile, the risk of interference from other sources renders this a least desirable option.

3. Wireless Modem

Wireless modems, also known as radio modems, are specifically designed for interconnecting two computers together. Physically, a wireless modem is a standard modem which has been modified to use radio waves rather than telephone lines as the medium for transmission of data. The radio consists of both a receiver and transmitter that operate simultaneously on separate frequencies to obtain full duplex operation. A typical radio modem configuration is shown in Figure 10. Commercially produced radio modems are available for 2400, 4800 and 9600 baud data rates. Disadvantages of wireless modems are their limited speed and inherent lack of ability to ensure error free communications. The error detection and correction must be performed external to the modem, usually by software in the communicating computers. Should the data throughput and integrity limitations be improved to meet Archytas speed requirements, this method could be a viable future consideration.

4. Packet Radio

Packet radio is similar to ethernet which provides physical connection, CSMA/CD, and a link layer protocol to ensure data integrity. One distinct difference between the ethernet card and packet radio is the physical architecture. The radio and the device that provides the interface between the computer and the radio are two separate entities. The

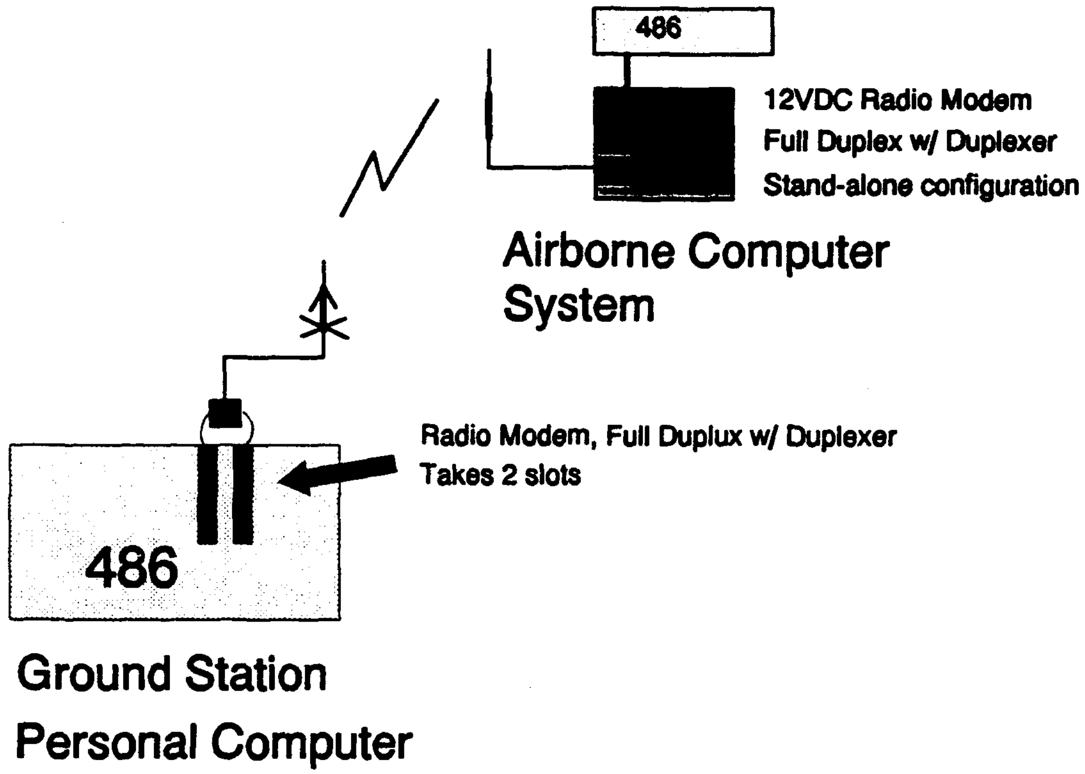

Figure 10 Typical radio modem configuration.

interface device, commonly referred to as a terminal node controller (TNC), contains its own processor, a high-level data link controller (HDLC), serial interface, memory, clock, and modem. A block diagram of the TNC is shown in Figure 11. TNC components relieve the personal computer of many communications management functions. The computer merely presents outgoing data to a serial output port for transmission and the TNC transparently performs all the communications management, including error detection and correction, and control of the radio transmit/receive switch. Incoming data is stored in the TNC until the computer calls

for it. The radio can be any radio that can provide appropriate bandwidth and switching times to support the data rate of the TNC.

Packet radio has been very popular among Radio Amateurs for the past ten years. As a result, TNCs for packet radio applications have become widely available at low prices. A 1200 baud TNC retails for as low as $50. The TNC speed is designed to fit within the bandwidth and deviation parameters of frequency modulated voice radios in the VHF and UHF Amateur Radio bands. Amateur Radio equipment retailers are offering higher speed TNCs, between 2400 and 4800 baud, but the higher data rates require wider bandwidth radios. Wide band radios have not been as readily available since most Amateurs can modify their existing radios to provide the bandwidth. At 9600 baud and beyond, specially designed wide band radios are required. As of this writing, only one Amateur Radio equipment manufacturer offers a 9600/19200 baud TNC and matching UHF FM wide band radio capable of handling the bandwidth required at a retail cost of about $800 for the TNC/radio pair. Prices for packet radio data links increase exponentially for speeds exceeding 19200 baud due to their high bandwidth requirement (exceeding that of the Amateur Radio privileges), low demand, and precision high speed switching components.

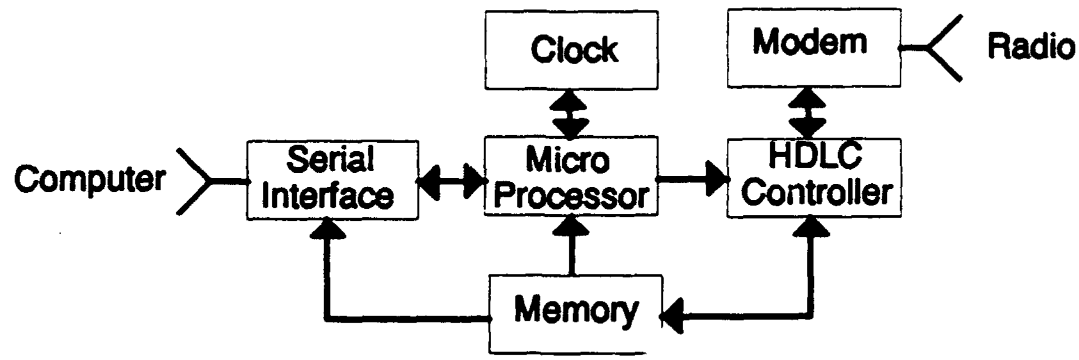

Figure 11 Terminal node controller block diagram

D. SELECTED SOLUTION

Packet radio is the selected solution since it best conforms to the data link selection criteria over the three other methods investigated. A market survey concluded that the only COTS packet radio that can transfer the required amount of data within budget is the Data Engine manufactured by Kantronics Co., Inc, Lawrence, Kansas. The complete configuration includes the Data Engine with the DE19K2/9K6 modem option and compatible D4-10 UHF Wide-Band Transceiver. A block diagram of the components and configuration of the packet radio solution is shown in Figure 12.

1. Solution Criteria Compliance

The Kantronics Data Engine with modem and D4-10 radio provide a wireless communications link. Power and weight requirements are within acceptable parameters provided circuit cards are removed from their cases and the D4-10 on the UAV is limited to 1 watt output. The link speed is 19,200 Kilobits per second which provides a 29% margin over the 14,812

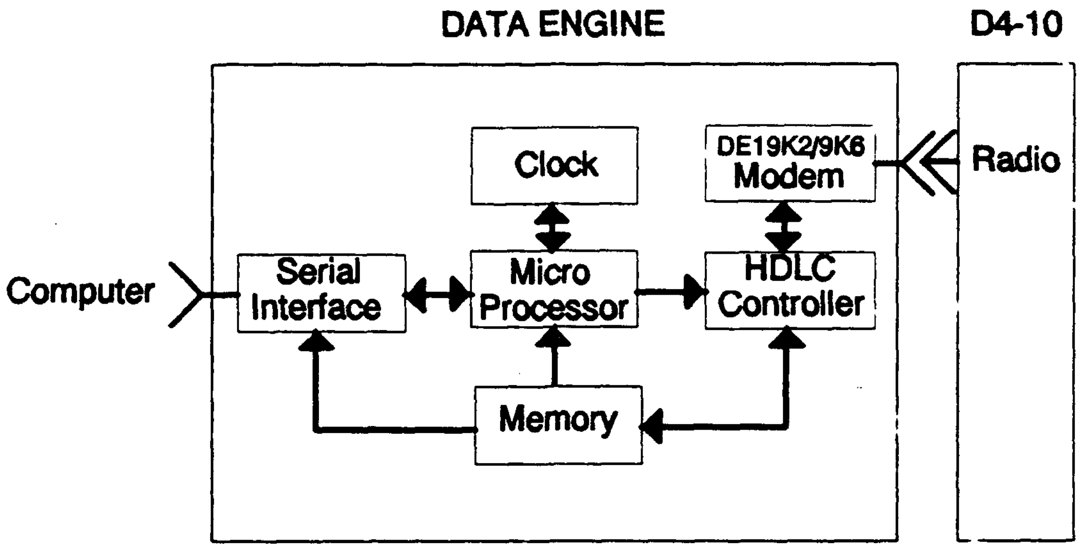

Figure 12 Data Engine and D4-10 Transceiver configuration

Kilobits per second required data rate. The Data Engine interface accepts EIA standard RS-232-D serial data connection as well as transistor-transistor logic (TTL). The three modular components (Data Engine, modem, and radio) allow for simple fault isolation and independent replacement. The UHF transceiver output is ten watts modifia!'e to one watt output. Even at tne one watt setting, using omni-directional antennas, the Archytas can maintain a point-to-point connection to the ground control station without relay throughout the operational range of the Archytas prototype. Figure 1? depicts the worst case link margin based on the gains and losses of the system components. Figure 14 shows the fade margins and reliability for both the UAV-to-Ground and Ground-to-UAV to a maximum range of 40 miles. As can be seen in the

figures, the data link will operate with a very high percentage of propagation reliability throughout the operating range of the UAV.

UAV Output = 1 watt	=	0.0 dBW
UAV Antenna Cable Gain	=	-0.5 dB
UAV Dipole Antenna Gain	=	0.0 dB
Free Space Path Gain (430.55 Mhz @ 40 miles)	=	-121.3 dB
Ground Station Antenna Gain	=	3.0 dB
Ground Antenna Cable Gain	=	-0.5 dB
Total power presented at receiver input	=	-119.3 dBW
Receiver sensitivity +12 dB SINAD	=	-143.0 dBW
Fade margin at maximum operating range	=	23.7 dB
Single-Hop Propagation Reliability for 23.7 dB	=	99.5 %

Figure 13 UAV-to-Ground Link Margin at 40 miles

		UAV-to-Ground (1 Watt)		Ground-to-UAV (10 Watts)	
Miles	Path Loss	Fade Margin	Reliability	Fade Margin	Reliability
40	121 dB	20 dB	99.2 %	30 dB	99.9 %
30	119 dB	22 dB	99.4 %	32 dB	99.95 %
20	115 dB	26 dB	99.7 %	36 dB	99.97 %
10	109 dB	32 dB	99.9 %	42 dB	99.99 %
5	103 dB	38 dB	99.99 %	48 dB	99.999 %

Figure 14 Link Fade Margins throughout the Operating Range

Although the circuit cards will not fit into the circuit card holder in the electronics pod, a complete data link package will fit easily between to struts on the outside of the Archytas duct. The Data Engine, modem and radio are commercially available products which are already well

established in the retail marketplace. The D4-10 radio is capable of two user selected frequencies based on standard size crystals which can be bought from both the radio manufacturer and other retail outlets. Crystal selection is limited to a 30 Mhz range without modification to the radio. To change the location of the 30 Mhz range requires modification to the oscillator and output circuitry of the radio. Frequency range of the D4-10, as stocked, is 420-450 Mhz. The hardware can be reconfigured to adapt to a change in requirements. (See Chapter V for anticipated enhancements.) The Data Engine has built-in software that controls the hardware functions and provides the communications protocols. Flexible software makes use of over one hundred parameters and commands which can be altered and saved in non-volatile memory called an erasable programmable read only memory (EPROM). The EPROM can be replaced should another operating program be desired. The Data Engine can accept temporary reprogramming by rewriting its programming while in operation. Packet radio is a proven technology. It was developed by the U.S. Advanced Research Projects Agency (DARPA) in 1969. The DARPA effort spawned both packet switching for wire based networks and packet radio which has been in use by amateur radio operators in the United States since 1980. (Horzepa, 1988, pp. 2-3) Technical support is available in the Monterey area through the Naval Postgraduate School Amateur Radio Club and from the manufacturer.

E. SUMMARY

Functional requirements for the Archytas primary data link could be best satisfied by commercial UAV telemetry products. The prohibitive cost forced recommendation of a more affordable, but less capable packet radio data link. In spite of the limitations of the packet radio solution, it does meet the criteria described in this chapter.

IV. TEST AND EVALUATION

Acquisition of specific data link hardware for the Archytas Vertical Take-Off and Landing (VTOL) Transitional Flight Unmanned Aerial Vehicle (UAV) prototype was based on reasonable expectations of functional requirement satisfaction. This chapter documents the functional capabilities based on test results. Also documented is the assembly and packaging of the acquired packet radio data link for use on the prototype Archytas.

A. ASSEMBLY

There are two assumptions and four essential components at each end of the Archytas packet radio data link. One assumption is that the data port on the computer will provide EIA standard RS-232-D serial port signals and levels. The second assumption is that a power supply capable of supporting the packet radio data link will provide the power within required tolerances. The four components at each end of the packet radio data link are the data engine, a modem, a transceiver, and an antenna. A block diagram at Figure 15 depicts the configuration for the ground station end of the packet radio data link. The UAV end of the link is a mirror image in concept. The diagram and following paragraphs depict the operations, assembly, configuration, interconnection and

switch settings of the various components of the link which are required before testing can commence.

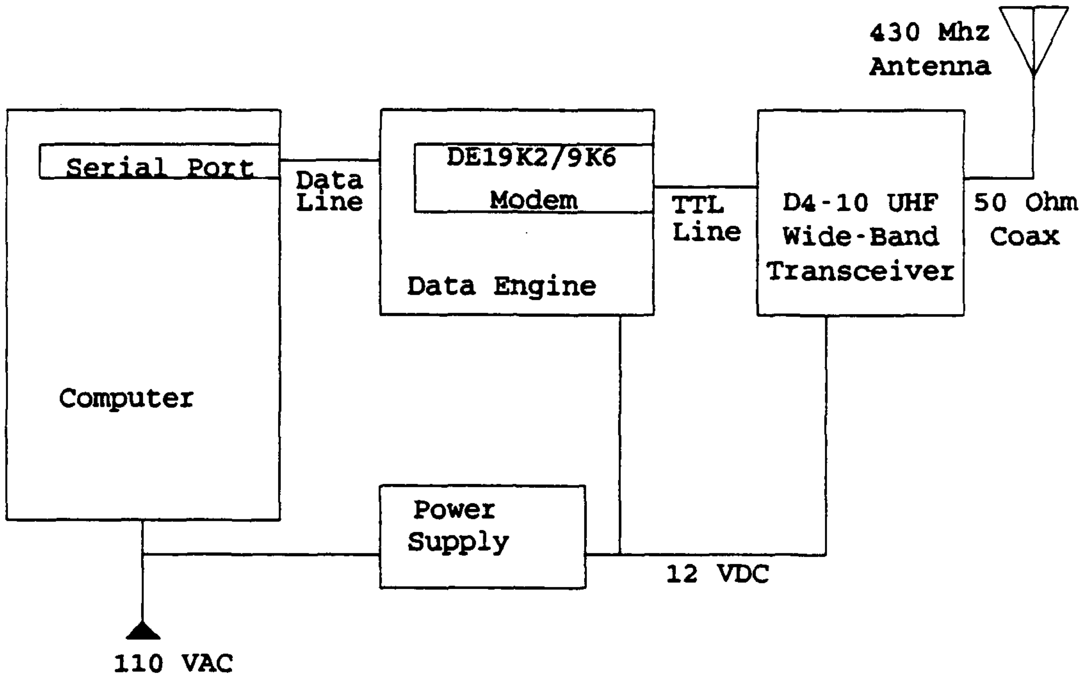

Figure 15 Ground Station Packet Radio Data Link Block Diagram

1. Data Cable

The data cable is a modular cable supplied with the Data Engine and terminated with a modular connector for the Data Engine RS-232 port. The other end is terminated with a Computer DB-9 or other connector compatible with the serial port output connector on the computer. As a minimum, pins 4 (Signal Ground), 5 (Receive Data), and 6 (Transmit Data) are connected. To allow the hardware to perform data flow control, pins 7 and 8, which providing data flow signalling,

are also connected. The Data Engine is considered Data Communications Equipment (DCE) and the computer is Data Terminal Equipment (DTE). Pin assignments and functions for each end of the data cable are shown in Figure 16. Arrows point toward the device receiving the signal being generated by the sending device.

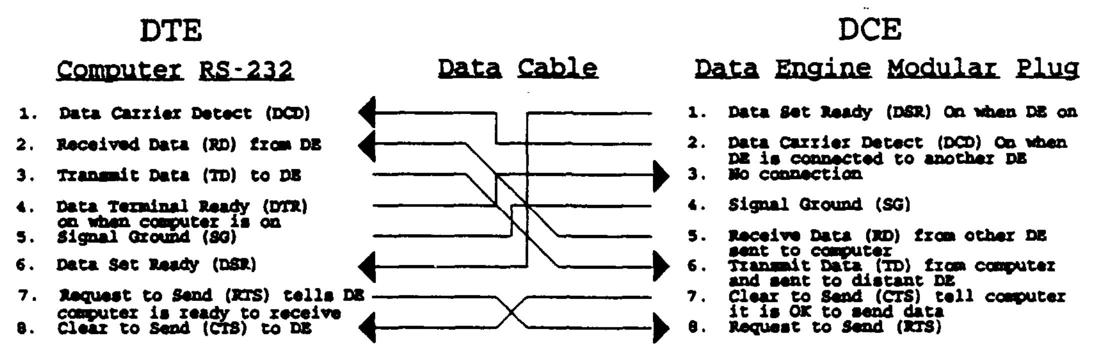

Figure 16 Data cable pin-to-pin connections and use

2. Data Engine

The Data Engine is a brand name for a Terminal Node Controller (TNC) whose hardware and software combine to implement AX.25 Version 2 Level 2 Packet protocol as adopted by the American Radio Relay League. Level 2 refers to the link layer of the International Organization for Standardization (ISO) seven-layered reference model of Open Systems Interconnection (OSI). (Fox, 1984, p iii). As a TNC, the Data Engine listens to the audio signals from the radio, changes data to digital form, determines if the data packet received is good, and sends the data to the computer. As a

sending device it receives digital data from the computer, packetizes it and changes it into audio tones (through the modem) which are sent to the radio for transmission. In order to perform these functions in accordance with the AX.25 protocol rules for error free transmission over a common radio frequency, the Data Engine consists of both hardware and software.

a. *Hardware Configuration*

The Data Engine hardware consists of three elements: The Data Engine circuit card, a modem piggy-back circuit card, and a metallic case. The modem option acquired from the Data Engine manufacturer for this project is a DE19K2/9K6 modem originally designed by James Miller and capable of either 9600 or 19200 baud signalling speed. The case provides for heat dissipation and is supposed to suppress radio frequency interference (RFI) which the Data Engine can cause to nearby electronic devices. The Data Engine card can be easily removed from the case. Modem attachments, power connector, indicator diodes and device connectors are integrated into the card and, except for the a power transistor, do not require attachment to the case. Although the Data Engine has two radio ports, only one will be used for the Archytas data link. Power to the Data Engine is supplied from an external 12 volt direct current source via the Molex power connector. The modem is installed for radio port 1.

The Data Engine is connected the D4-10 radio via a TTL cable using the DB-15 connector clearly marked on the back of the Data Engine as Port 1. There are two front panel switches; power and Aux. The Aux switch should not be depressed into the test mode at any time.

b. Software Configuration

The heart of the Data Engine is a micro processor that controls the hardware. When power is applied to the Data Engine and the power switch is depressed, an instruction set is copied from an erasable programmable read only memory (EPROM) into a volatile random access memory (RAM). The RAM holds the instruction set until power is lost. Once the instruction set is in RAM, the micro processor begins to execute the instructions, setting the RS-232 and radio ports to the programmed configuration, monitors the radio ports, and then waits on further commands from the computer. At this point, parameters which determine how data will be handled can be changed. Once changed to the desired settings, all parameters can be stored in the non-volatile EPROM by issuing a PERM command from the computer to the Data Engine micro processor. Subsequently, if power is lost, then reapplied, the latest setting of the parameters will be in effect. To establish a data link from the ground station computer to the UAV, a request for virtual connection must be made. The connection need only be initiated from one end of the link.

Once the virtual connection is established, the link becomes a virtual bi-directional link. To minimize requirements for control of the link by the UAV, control will be performed from the manned end of the link at the ground station computer. This is a master-slave relationship where the ground station computer and Data Engine is the master and the UAV the slave. Due to this relationship, parameter setting will differ between the UAV and ground station. Preliminary parameter settings that were chosen based on manufacturer recommendations and experience of the author are shown in Figure 17. The parameters shown are those that differ from the default settings or where the parameters of the UAV end of the link differ from that of the ground station.

3. TTL Cable

The cable connecting the Data Engine to the D4-10 UHF Wide-Band Transceiver carries transistor-to-transistor logic (TTL) level signals. This cable should be kept as short as possible. The manufacturer of the link equipment recommends that the cable be no more than 24 inches of shielded cable. The connector is terminated with commercially available DB connectors. The radio port on the data engine requires a DB-15 connector. The TNC port of the D4-10 radio requires a DB-9 connector. Pin assignments and functions for each end of the cable are shown in Figure 18. Arrows point toward the device receiving the signal generated by the sending device. No

UAV Data Engine Parameters		Ground Data Engine Parameters	
Autolf	OFF	A	ON
BPath	(empty)	BP	(empty)
BReak	OFF	BR	ON
CMdtime	0	CM	1
CONMode	T	CONM	T
CPactime	ON	CP	ON
CR	OFF	CR	ON
DIGipeat	OFF	DIG	OFF
DISCMode	NONE	DISCM	COMMAND
ECHO	OFF	ECHO	ON
Flow	OFF	F	OFF
FLOWR	OFF	FLOWR	OFF
FLOWX	OFF	FLOWX	OFF
FRack	4	FR	2
HId	OFF	HI	OFF
Leds	OFF	L	ON
MAxframe	7	MA	7
MAXUsers	1	MAXU	1
MHeard	2	MH	2
MO	19200,N,8,1	MO	19200,N,8,1
MODEM	(set internally)	MODEM	(set internally)
Monitor	OFF	M	OFF
MONList	NONE	MONL	NONE
MONType	NONE	MONT	NONE
MYcall	NPS1	MY	NPS2
Paclen	256	P	256
PERSist	255	PERS	255
RETry	0	RET	0
RIng	OFF	RI	OFF
TXdelay	3	TX	3
Unproto	TEST	U	TEST

Figure 17 Initial Data Engine parameter settings

other pins should be used.

4. D4-10 Radio

The D4-10 UHF Wide-Band Transceiver is similar to the Data Engine in construction. The entire transceiver is on a printed circuit board which can be removed and operated independent of its case provided suitable heat sinks are applied to power transistors. There are four front panel

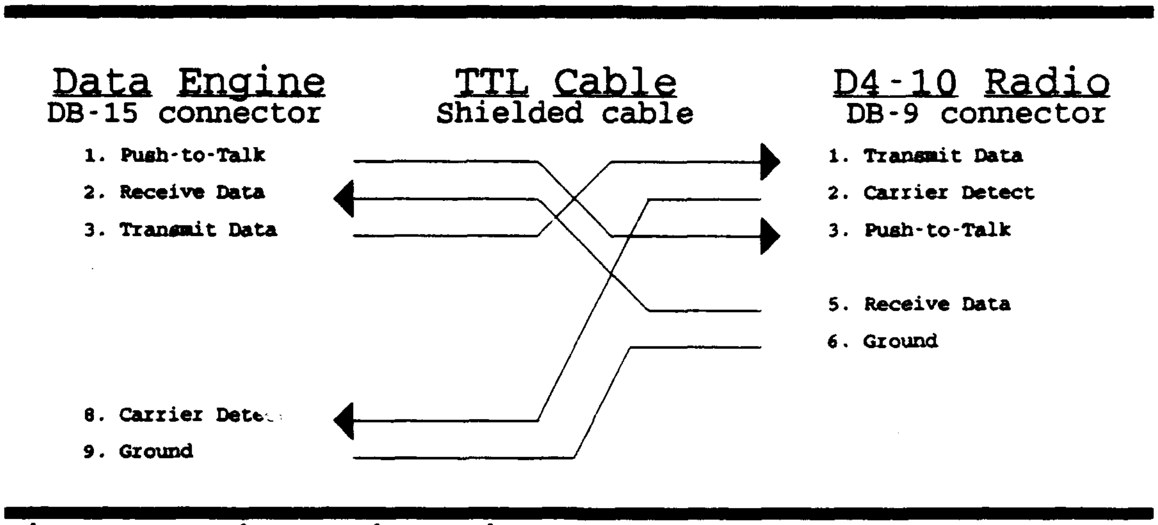

Figure 18 Pin-to-Pin assignments for TTL Cable

switches; power, channel (CH), bandwidth (BW), and satellite (SAT). The D4-10s for the Archytas were acquired with two crystal controlled frequencies; 430.55 and 430.95 Mhz. The channel selector is a push-push switch. Channel 1 (430.55 Mhz) is selected when the CH switch is out. The BW switch selects either a narrow 455 KHz ceramic filter for the last intermediate frequency and a 60 KHz discrete linear-phase filter for wide-band use. At the 19,200 baud rate, the wide-band setting, with the push-push switch out, is required. The SAT push-push switch enables the receive local oscillator to adapt to doppler-shift conditions. This function is not required and the switch should be out. The TTL cable from the Data Engine is connected to the TTL Port at the back of the D4-10. The D4-10 requires 12 volts direct current applied to the power port using a Molex power connector. The antenna

connection is a BNC female and requires an impedance load of 50 ohms.

5. Antenna

Antennas, including feed lines to the D4-10 radios, are required to be resonant between 430 and 431 MHz at 50 ohms and present a standing wave ratio of no more than 1.2:1. This is a self-imposed requirement to ensure that as little of the radio energy is being turned to heat, spurious emissions are reduced to a minimum, antenna gain is maximized in the desired direction, and that the transmitter is running as efficiently as possible.

B. BENCH TEST

To verify that all equipment and cables were functioning correctly and to obtain a baseline of capabilities of the Archytas configuration, four bench tests were conducted. Tests measured data throughput speed, bit error rates, power consumption, and total weight. Bench tests used the configuration and parameter settings described in the Assembly section above.

1. Throughput Speed Measurement

Throughput speed is a measurement of the number of usable information bits transferred from one computer to another through the Archytas data link under ideal conditions. Baseline throughput speed is the worst case of either unidirectional data transfer or simultaneous bi-directional

data transfer. The worst case is used to ensure that the design of the computer programs that rely on data transfer do not demand data transfer at a higher rate than the data link is capable of delivering. Throughput speed equates to the total number of information bits transferred from computer port to computer port through the link.

a. Test set up

Both ends of the data link were configured identically and as depicted in Figure 15. The stations were separated by one hundred feet. The computers used in the test were Intel 486 micro processor based personal computers running identical terminal emulation programs capable of performing data transfers. Asynchronous serial port parameters were set to 19200 baud, 8 data bits, no parity, 1 stop bit. Test files were various length files of pseudo-random ASCII characters. After setting each Data Engine with the desired parameters as specified in Figure 17, the Data Engines were placed in the transparent mode for data transfer. Two types of tests were conducted. The first test determined throughput speed based on mean time to transfer test files from one personal computer to the other. A stopwatch was used to measure the elapsed time from the start of the file transfer on one computer until the last bit was received on the second computer. This test was conducted ten times to determine the mean throughput speed based on elapsed file

transfer times. Uni-directional throughput speed equates to the transferred file size in bits divided by the elapsed time of the file transfer. The second test determined throughput speed based on mean time to transfer copies of the test file in both directions at the same time. File transfers from each end of the link and the stopwatch were all started simultaneously. Elapsed time ended when the last bit was received regardless of which computer received it. This test was conducted ten times and the elapsed time used to determine throughput speed. Throughput speed equates to the total number of bits transferred divided by the elapsed time of the transfer. All tests were conducted again with stations separated 2 miles but within visible line of sight. The UAV end employed a quarter wave vertical antenna. The ground station employed a double skirted ground plane antenna.

Results were expected to be less than 19,200 bits per second of computer-to-computer information bits. Even if the data link was able to transfer all data presented to it at 19,200 bits per second, the connection between the computer and the Data engine can transfer information data bits at only 73% of the set asynchronous data rate. Each 8-bit character sent between the computer and the Data Engine is packaged in an 11-bit string. Figure [illegible] shows the format of each character. Since only 8 of the 11 bits are actually transmitted by the data link, a 19200 asynchronous data rate

between the computer and the Data Engine limits the information bit rate to approximately 13964 bits per second.

Start Bit	8 Data Bits								Stop Bits	
1	1	1	1	1	1	1	1	1	1	1

Figure 19 Asynchronous character format

b. Uni-Directional Throughput Results

Throughput tests were conducted with various length files to test TNC parameter settings for minimum delay. Parameters that yielded the highest throughput were recorded and the lists are included in Appendix B. Tests for speed were first done with a file with 34,749 bytes of text characters so that errors could be detected by viewing monitors attached to the computers. Results of the tests are listed in Figure 20.

The file transfer was satisfactory but timing proved to be difficult since the transfer timings were initiated at one site and stopped at the other. Throughput was measured as low as 11,583 bits per second and as high as 13,237 bits per second. A one second error in timing changed the outcome by 550 bits per second. For that reason, a longer file was used for the timing test. The results of ten 100,000 byte file transfers is shown in Figure 21.

Using the 100,000 byte file, a second error in timing represented only a 218.5 bits per second difference,

TRIAL	FILESIZE	BITS	SECONDS	BPS
1	34749	277992	21	13237.7
2	34749	277992	23	12086.6
3	34749	277992	22	12636.0
4	34749	277992	22	12636.0
5	34749	277992	23	12086.6
6	34749	277992	21	13237.7
7	34749	277992	23	12086.6
8	34749	277992	24	11583.0
9	34749	277992	22	12636.0
10	34749	277992	22	12636.0

TRIALS	MEAN	MEDIAN	MIN	MAX
10	12486	12636	11583	13238

Figure 20 Uni-directional transfer results with a small file

TRIAL	FILESIZE	BITS	SECONDS	BPS
1	100000	800000	60	13333.3
2	100000	800000	60	13333.3
3	100000	800000	59	13559.3
4	100000	800000	60	13333.3
5	100000	800000	61	13114.8
6	100000	800000	59	13559.3
7	100000	800000	60	13333.3
8	100000	800000	61	13114.8
9	100000	800000	61	13114.8
10	100000	800000	60	13333.3

TRIALS	MEAN	MEDIAN	MIN	MAX
10	13313.0	13333.3	13114.8	13559.3

Figure 21 Uni-Directional transfer results with a large file

less than half the error with the smaller file. The throughput ranged from 13,112 to 13,559 bits per second with a mean of 13,313 bits per second.

c. *Bi-Directional Throughput Results*

Several commercially available communications software programs were used during the assembly, set-up, and test phases, yet none of the programs had the capability to perform simultaneous bi-directional data transfers. Data transfers could be initiated from each end of the data link at the same time, but the other end of the link would ignore incoming data until the outgoing transfer was complete. Accuracy of the bi-directional file transfers could not be verified but the tests were conducted anyway. The indicator lights and end-to-end voice communications were the only cues that a file transfer was complete. Asynchronous serial port parameters between the computers and the Data Engines were changed to 9600 bits per second for this test. The entire contents of the 34,749 byte file were sent from each end of the link for a total of 69,498 bytes transferred. The results of the bi-directional test are shown in Figure 22. The bi-directional test indicated that total throughput is not affected by the opposing data flows.

2. Power Consumption Measurement

Power consumption was measured during the throughput speed tests. Power consumption was the peak DC amperage drawn as measured by a Realistic solid state ammeter of the DC circuit feeding both the Data Engine and the D4-10 radio. Peak current draw occurred while the D4-10 radio was

TRIAL	FILESIZE	FILES	BITS	SECONDS	BPS
1	34749	2	555984	40	13899.6
2	34749	2	555984	41	13560.6
3	34749	2	555984	40	13899.6
4	34749	2	555984	40	13899.6
5	34749	2	555984	41	13560.6
6	34749	2	555984	41	13560.6
7	34749	2	555984	41	13560.6
8	34749	2	555984	40	13899.6
9	34749	2	555984	40	13899.6
10	34749	2	555984	41	13560.6

TRIALS	MEAN	MEDIAN	MIN	MAX
10	13730.1	13730.1	13560.6	13899.6

Figure 22 Bi-Directional Transfer test results

transmitting at full power (measured at 10 watts) and was measured at 2.6 amperes. Reducing RF output power to 1 watt should reduce the power consumption to 1 ampere. The Data Engine alone pulled 100 milliamps which did not change whether the Data Engine was idle or performing a data transfer. The D4-10 radio consumed 184 milliamps while receiving data. The reading was the same when no data was present.

3. Total Weight Measurement

Individual components of the data link were weighed and measured to determine the total weight of the UAV end of the link only. The Data Engine and D4-10 Transceiver boards were removed from their cases for dry weight measurements. The UAV weights and measures are listed in Figure 23. The total operating weight of the UAV end of the data link is 3.94 pounds which is nearly a pound over the link total weight

limit of three pounds. Reducing output power to 1 watt equates to 0.896 pounds of weight reduction. At the lower power output, the D4-10 would not need the heat sink which saves another 0.75 ounces. Total weight of the link would then be around 3.00 pounds.

UAV Configured Data Link @ 10 Watts Output

Dry Weights		Power Weights	
Data Engine	13.75 oz	Data Engine	0.1 Amp
Shielding wrap	2.00 oz	D4-10	2.6 Amp
D4-10 Radio	10.75 oz	Total power	2.7 Amp
Shielding wrap	2.00 oz		
Heat sink	0.75 oz		
Cable assembly	6.75 oz		
Antenna	3.00 oz	Power to weight conversion	
Total weight	39.00 oz	2.7 Amp x .56 =	24.19 oz

Dry weight + power weight = 39.00 + 24.19 = 63.19 oz
= 3.95 lbs

Figure 23 Data link weight measurements

C. INSTALLATION

The Data Engine, with modem board, and D4-10 radio are too heavy to be placed onto the Archytas without removing the components from their cases. To shield the circuit boards both electrically and mechanically, each board assembly has been wrapped in anti-static plastic then enclosed in thick copper foil. The indicator lights and front panel switches have been left exposed under a copper flap which can be left

open for testing and switch setting, but closed for operation. Necessary connectors have also been left exposed without a cover flap. The D4-10 has the addition of an exterior heat sink over the transmitter power amplifier for rapid heat dissipation. The boards can be mounted side-by-side or on top of each other and attached to the exterior of the Archytas duct by using plastic strapping.

V. INCREASING SPEED AND CAPABILITIES

This chapter is intended to present feasible, near-term enhancements to the data link presented in Chapter IV. Enhancements such as conversion to full duplex, reduction of protocol overhead, data compression, and increasing the modem speed are enhancements intended to improve the end-to-end data transfer speed. A device driver algorithm is presented to aid the on board computer processor unit (OB CPU) programmers with a method for handling the data exchange between the OB CPU and the data link. Finally, information is presented on the process for relocation of the data link operation to a military frequency.

A. CONVERSION TO FULL DUPLEX

The data link configuration as built in Chapter IV is a half duplex link but can be enhanced to operate in the full duplex mode. The Kantronics Data Engine is a dual port device. The data link presented in Chapter IV uses only one port. The radio attached to that port is either in the transmit or receive mode. It cannot perform both functions at the same time. When data is being sent in two directions at the same time, total throughput speed is less than the 13,335 bits per second single direction data throughput speed. A

diagram of the functional components of the data link are shown in Figure 24.

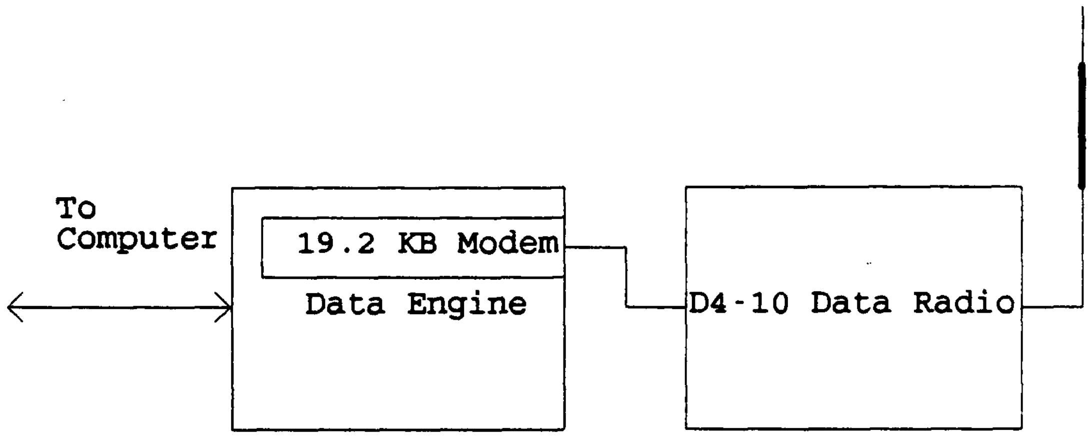

Figure 24 Present single modem and radio configuration

To overcome the limitation, a second data radio is required. It should be designed to operate on a separate band to avoid interference with the first data radio. Any 100 KHz wide channel on a frequency above 600 Mhz will work provided that the selected frequency is not within 100 KHz of a second or third harmonic of the center frequency of the original data radio. The second data radio will require its own modem and port in the Data Engine. Another DE19K2/9K6 modem installed in Port 2 can be configured so that incoming data would be received through one port while outgoing data is sent to the other port. A peak throughput data rate of 26,670 bits per second can be achieved since both ports would be engaged in simultaneous 13,335 bit per second average speed, single direction data transfers on their own frequencies. A diagram

of the configuration with the additions highlighted is shown in Figure 25.

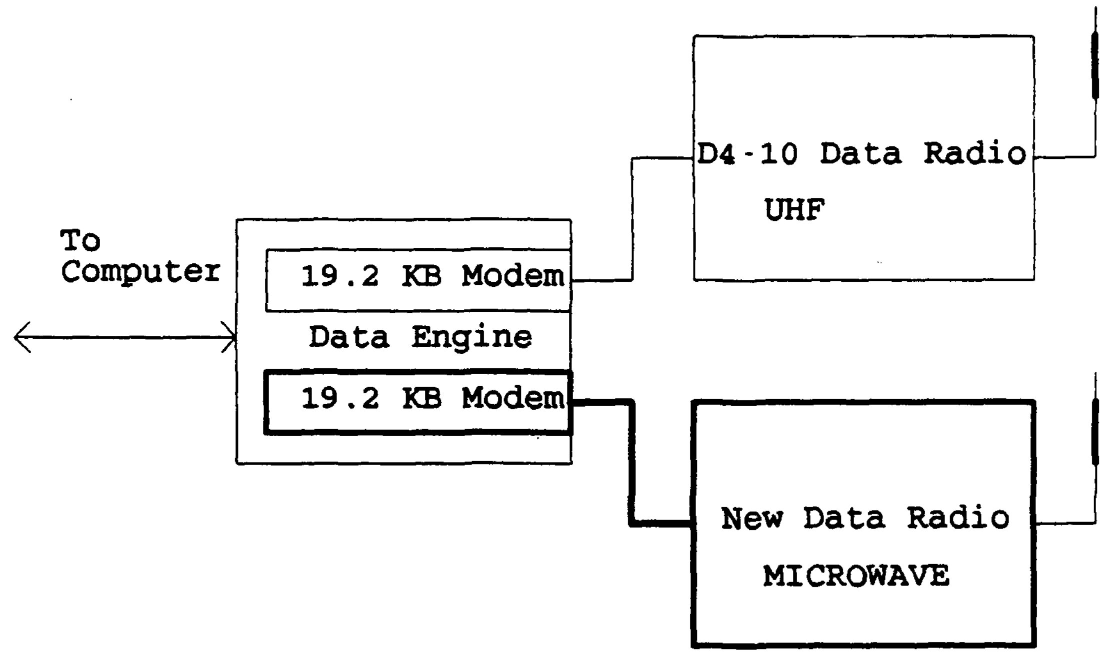

Figure 25 Dual radio, dual modem, full duplex configuration

B. REDUCTION OF PROTOCOL OVERHEAD

The Data Engine's non-volatile read only memory (ROM) contains the AX.25 Amateur Packet Radio Protocol for TNC-to-TNC communications. The ROM can only be changed by physically removing the integrated circuit chip and replacing it with another ROM. When the Data Engine is turned on, the contents of the ROM are read into volatile random access memory (RAM). The RAM is accessed by the micro processor which runs the communications algorithm. The algorithm, once begun and in the command mode, can be altered, erased or replaced. This

can be accomplished through the UPLOAD command feature as found in the Data Engine Operator's Manual and detailed in the Data Engine Developer's Manual.

The AX.25 protocol was designed for point-to-point communications on a shared channel in the Amateur Radio bands. When the data radios are tuned to a clear military frequency, the data link is neither sharing the frequency nor required to identify according to Part 97 of the Federal Communications Commission rules governing Amateur Radio. Since there are only two stations in the network, they always know who the other station is and what level of protocol is being used. Originating and destination station identification and the Protocol Identifier (PID) fields, which are sent with every packet, are no longer necessary. A full size 256 character AX.25 information packet, with overhead, is 2,208 bits long. The components of an information packet are shown in Figure 26.

Flag	Address	Control	PID	Data	FCS	Flag
8	112	8	8	2048	16	8

Numbers are bits per item.

Flag 01111110
PID Protocol Identifier
Control Identifies the type of frame
FCS Frame-Check Sequence for error checking

Figure 26 AX.25 Information Packet

By eliminating the address and PID fields, the packet frame is only 2,088 bits long. The data between the OB CPU

and the ground station computer becomes 98.08% of the frame versus 92.75% when the address and PID fields are used.

C. DATA COMPRESSION

Data throughput speed can be increased by employing physical data compression techniques.

> Physical compression takes advantage of the fact that when data is encoded as separate and distinct entities, the probabilities of occurrence of characters and groups of characters differ. Since frequently occurring characters are encoded into as many bits as those characters that only rarely occur, data reduction becomes possible by encoding frequently occurring characters into short bit codes while representing infrequently occurring characters by longer bit codes. (Held, 1987, p. 3)

The present configuration requires the encoding and decoding of compressed data be performed external to the data link. The data link merely transfers bits, either ones or zeros, from one end of the link to the other. Every eight bits in the information portion of the data frame represents one character, but the data link makes no distinction as to the nature of the character. Only the computers at each end need to see the characters in their natural state. Data compression reduces the readable characters to groups of coded characters that increases throughput by eliminating redundant characters and repeating bits being transmitted. At the receiving end, the data is decoded to its original state and passed onto the computer. Most of the data to be sent between the UAV and the ground control station will be numbers. Data compression and expansion is a proven technique and is a

commonplace application for personal computer use. A run length data compression/expansion algorithm which greatly reduces file size for hard disk storage can obtain as much as a 3:1 ratio of natural to compressed size files. Likewise, many telephone modems, such as those complying with the V.42 bis Consultative Committee on International Telephone and Telegraph (CCITT) standard, perform data compression to obtain data throughput which is higher than the actual link speed.

D. FREQUENCY MANAGEMENT

The Kantronics D4-10 was delivered with two frequency crystal sets installed for operation on 430.55 MHz and 430.95 MHz. These frequencies are in the US Government radio location (RADAR) band and are sanctioned for use by target drones. It is also assigned for use by Radio Amateurs on a secondary basis. The data link is being used under the secondary use basis under the auspices of several Federal Communications Commission licensed Radio Amateurs participating in the Archytas project as an experimental amateur packet radio link. The frequencies available in the D4-10 are two of nine 100 KHz channels in the 420-450 MHz band that have been approved by the American Radio Relay League in 1988 and incorporated into the band plan for high speed packet radio use.

As the popularity and availability of higher speed Amateur packet radio devices increases, so too will the use of the

same frequencies that the Archytas data link now uses on an almost exclusive basis. To avoid the possibility of interference to the Archytas data link operation, frequencies in the military telemetering and terrestrial telecommand bands should be requested now, and radios capable of operation in those bands should be procured as soon as funds are made available. Archytas data link operations are authorized in the bands 3100-3700, 5250-5925, 8500-10,000 MHz, 13.4-14.0 and 15.7-17.7 GHz. Requests for frequencies for use by the US Navy are made in accordance with Naval Telecommunication Publication 6, Spectrum Management.

VI. OPERATIONAL ARCHYTAS DATA LINK CONSIDERATIONS

If the Archytas prototype proves to be a viable UAV concept and is adopted for further development by the Department of Defense, many enhancements will be required before the Archytas can perform in an integrated military operational environment. This chapter is intended to serve as an overview of data link design considerations for the acquisition of an operational UAV based on the prototype Archytas vertical take-off and landing (VTOL) transitional flight UAV concept. These considerations are presented with the perspective that the time line for development of an operational Archytas will coincide with advanced developments in technology and a fully integrated joint command, control, communications and intelligence architecture for the warfighters.

A. OPERATIONAL REQUIREMENTS BASELINE

An operational Archytas would serve to increase the combat effectiveness of the ship or fleet it serves. To this end, the operational Archytas would not merely be an independent entity, commonly referred to as a "stovepipe" system, consisting of the UAV and a dedicated shipboard control station. The maturity of the prototype into the operational

Archytas would be part of a program which is developing a family of UAVs.

> Our Unmanned Aerial Vehicle (UAV) program will develop a family of UAVs with specific range and payload capabilities to accommodate a variety of needs from small unit, over-the-hill reconnaissance to much deeper, over-the-horizon surveillance. (Powell, 1992)

Joint service operations requires common and interoperable UAV systems. An operational Archytas would be such a system.

> Recognizing the need for common and interoperable systems, Congress in 1988 directed the Department of Defense (DoD) to consolidate the management of DoD nonlethal UAV programs and to prepare an annual UAV Master Plan. (UAV 1993 Master Plan, p 1)

The UAV 1993 Master Plan provides a summary of the Operational Requirement Document (ORD), as staffed in DoD, that expands upon the Mission Need Statement (MNS) baseline for UAVs. The portion of the ORD that applies to Vertical Take Off and Landing (VTOL) UAVs, as it appears in the UAV 1993 Master Plan, is listed below in Figure 27. Although data link requirements for anti-jam capability and ship compatibility are explicitly mentioned, there are additional requirements implicitly imposed on the data link that must be met in order to support the other baseline items. These items are mission, radius of action, payload capacity, sensors, growth, and endurance. Both the explicit and implicit data link requirements translate into criteria that guide development of the operational Archytas architecture and systems engineering. Design and implementation of the data link must be done as an integral part of the overall multi-

service war fighting system; able to coexist with existing systems on a non-interference basis. Information collected or originated by the operational Archytas must be made available to all friendly entities that can make use of such information. This requires the Archytas system to be designed so that it is fully integrated into a multi-service (joint) command and control information system architecture. Additionally, there are optional enhancements not mentioned in the UAV 1993 Master Plan which should be considered in the operational Archytas design to ensure future growth potential and mission security. Those items are discussed as tertiary requirements. Explicit, implicit and tertiary design and engineering criteria are listed in Figure 28 and are discussed below.

1. Explicit Data Link Requirements

The UAV 1993 Master Plan explicitly states two operational requirements for a VTOL UAV data link: Ship Compatibility and Anti-Jam capability.

a. Ship Compatibility

Operation of any electronic device, especially one that produces and uses radio frequencies, has two major goals. First, the device must not interfere with any ongoing operations of any other shipboard radio frequency dependent devices. Electromagnetic interference (EMI) between UAV systems and other friendly emitters was a significant problem

Service	**United States Navy (USN)** **United States Army (USA)** **United States Marine Corps (USMC)**
Service Organizational Level	**Ship (USN)** **Marine Expeditionary Brigade (USMC)** **Marine Expeditionary Unit (USMC)**
Mission	**Over-the-Horizon Target Detection, Tracking and Classification** **Anti-Ship Missile Defense**
Radius of Action	**208 KM (110 NM)**
Payload Capacity	**200 LBS**
Sensors	**Imagery, Radar, and Electronic Counter Measures (ECM)**
Growth	**Signals Intelligence (SIGINT)** **Communications Relay** **Target Designation**
Endurance	**5-6 HOURS**
Launch/Recovery	**VTOL**
Ground Station	**Ship/(Vehicle)**
Takeoff Gross Weight	**1,500 LBS**
Air Speed	**135 KNOTS**
Altitude	**12,000 FEET**
Data Link	**Ship Compatible,** **Anti-Jam Capability**

Figure 27 VTOL UAV Operational Requirements Baseline

encountered during Operation Desert Storm. (KARCH, 1991) Ship topside space is very limited and has a densely cluttered electromagnetic spectrum. New emitters should not add to the problem. Second, new ship systems must be operationally compatible with existing systems. Although the UAV Joint

Explicit Data Link Operational Requirements

- Ship Compatibility
- Anti-Jam Capability

Implicit Data Link Operational Requirements

- Over-the-horizon operation to 208 km
- Anti-ship missile defense integration
- Minimum impact on 200 LBS payload capacity
- Air traffic control integration
- Highly efficient for six hour mission endurance
- Wideband downlink for sensor data
- Large margin to support growth items

Tertiary Data Link Operational Requirements

- Modular design for plug and play capability
- Simultaneous multiple mission support
- Link encryption
- Low probability of detection/interception

Figure 28 System design and engineering considerations

Program Office expects to publish a capstone specification in FY93 that defines the system architecture (UAV 1993 Master Plan p.54), an interim solution for shipboard integration for testing has already been defined:

> Use of existing antennas is the optimum solution to this problem and studies have indicated that the Light Airborne Multi-Purpose System (LAMPS) MK-III data link (AN/SRQ-4) may be compatible with short range (SR) UAV datalinks. The systems integration effort will integrate a modified AN/SRQ-4 with a USN TAC-3 based workstation which will host SR UAV software. (UAV 1993 Master Plan, p 43)

The interim system is the first step toward integration of ship launched and recovered UAVs into existing AN/SRQ-4 and TAC-3 shipboard command and control systems.

> The VTOL UAV will incorporate the requirements of the UAV family architecture, achieve operational interoperability through incorporation of Joint Integration Interfaces (JIIs), and will provide USN, USMC, and USA an organic, tactical reconnaissance, surveillance and target acquisition (RSTA) capability. The VTOL system for naval applications focuses on integrating SR UAV system software and hardware into ship subsystems. Thus, USN and USA forces may operate either the SR UAV or the VTOL UAV using organic command and control assets or may share resources and exchange air vehicles with another Service's control stations. The air vehicle will be a high speed VTOL capable of carrying imaging sensors common with the SR and Close Range (CR) UAV programs, incorporating SR command and control and video down link to ensure interoperability. (UAV 1993 Master Plan pp 41-42)

b. Anti-Jam Capability

Performing the necessary engineering that reduces the effectiveness of hostile activity aimed at rendering a data link ineffective through jamming has the additional benefit of reducing the effects of mutual interference from friendly emitters. Anti-jam solutions include the employment of spread spectrum, frequency hopping, and steered beam antenna techniques. The goal of an anti-jam capability is to ensure that the data link is able to maintain the minimum

essential level of data throughput in spite of the presence of other emissions, whether deliberate or unintentional.

2. Implicit Data Link Requirements

Baseline requirements for the VTOL UAV, such as mission, radius of action, payload capacity, sensors, growth, and endurance, impose restrictions on the physical and electrical aspects of the data link while increasing the minimum level of capabilities the data link must satisfy. It is imperative for the Archytas systems engineer to correlate the baseline requirements into implicit data link requirements.

a. *Mission and Radius of Action*

The baseline mission requires a VTOL UAV to perform over-the-horizon target detection, classification and tracking out to the UAV operating radius of 208 km. However, primary frequency allocations for the DoD's Common Data Link (CDL) and the Joint Data Distribution System (JTIDS) are in the C, L, and X microwave bands. Microwaves are space waves and as such propagate in a linear, line-of-sight manner only in ideal conditions. Space waves are affected by the pressure, temperature and humidity of the troposphere. The rate of change of these variables with respect to altitude determines the degree of refraction of the space wave. (Babcock, 1990, p. 13) Common effects of refraction are ducting, the trapping of spacewave signals in narrow layers of

the troposphere, and the bending of the spacewave either upward away from the earths surface or down toward it. Effects of refraction can degrade or sever direct communications between the UAV and its host ship. One possible solution is a communications relay. Delay tolerances through communications relays must be considered and may not be acceptable for the UAV's anti-ship missile defense role. Another solution is to provide for an on-board data recorder and fall back flight parameters so that the UAV will record vital payload product information until communications is re-established. Again, this solution may not be acceptable for an anti-missile defense system. If the UAV can no longer communicate directly with the ship, most likely the ship cannot see the air space with its radar either. Air traffic coordination and mission deconfliction will need consideration.

b. Sensors and Growth

In addition to considering how the payload will be controlled is the question of who will be in control. In a fully integrated combat system, of which the UAV host ship will be just a part, the ship may act merely as a UAV launch, recovery, and communications relay platform for a command and control system located elsewhere. For example, the command for an over-the-hill reconnaissance mission may be initiated from an Army or Marine unit ashore with the UAV control being

performed by the Air Force as part of the automated air tasking order. The intelligence gathered by an imaging sensor aboard the UAV will accomplish the over-the-hill reconnaissance for the battlefield commander by locating automatic weapons emplacements and armor vehicles in defilade. At the same time, the imaging may also be used by theater intelligence to identify the enemy force, by the Air Force to access battle damage from a recent air strike, and the Navy to set up battlefield preparatory fires from battleship guns. This can only be done through the use of a common data link (CDL). The CDL is common in two ways. First, data from sensors for imagery, radar, and electronics counter measures are handled in an identical manner so that common equipment can be used to make use of the UAV supplied information regardless of the sensor being used. Second, the same ground equipment can be used to decipher the data from a UAV regardless of the UAV being employed at the time.

c. Payload Capacity and Endurance

Data link size, weight, power consumption, and capabilities are factors in the payload capacity and endurance equations. Ideally, the physical size, weight and power consumption of the data link should be as close to zero as possible to maximize the availability of those same resources for the payload. The UAV and its data link are, after all, just the vehicle. It is the payload that performs the

missions and develops the product the users need. However, it is the data link that delivers the product. Size and weight of the data link equipment, beyond that which carries flight control and instrument data, should be counted as part of the payload capacity. Endurance time of five to six hours is the total flight time per sortie. Considerations for the data link power supply, whether battery, alternator, or other source, should include enough reserve to provide full operating power beyond the maximum endurance time to ensure that the UAV can exchange flight data until the UAV has safely landed.

3. Tertiary Data Link Requirements

The explicit and implicit data link requirements garnered from the UAV 1993 Master Plan are not an all inclusive list of considerations for an operational Archytas data link design. Considerations not discussed are those that add security and convenience for extended operation of the UAV. Security considerations include communications security (COMSEC) to reduce the possibility of eavesdroppers and spoofers, and transmission security (TRANSEC) to reduce the possibility of hostile destruction of the UAV. Convenience considerations include the modular design of the data link and automated take-off and landing.

a. Communications Security

If an enemy can detect the radio transmission of a UAV, they can intercept the data link information or spoof the UAV to perform activities other than intended by friendly forces. By intercepting a datalink exchange from the UAV, an enemy force can determine how they are being seen or detected from the UAV perspective and react accordingly. By seeing the angle of a particular look, an enemy can determine the UAV's location and shoot it down or use cover and concealment to present a decoy or feint to the UAV. An encrypted data link, employing an integrated (built-in) communications security (COMSEC) algorithm would decrease the likelihood of interception of UAV payload product information.

Both directions of data link activity should be encrypted so that only friendly activities would then have control of the UAV. Without the security feature, a resourceful adversary could commandeer the UAV or spoof the UAV into providing false or misleading information to friendly command and control system.

b. Transmission Security

The ideal COMSEC is to transmit and receive radio signals in a manner that denies the enemy both the capability to detect, intercept or interfere with those signals. The discipline to achieve this end is transmission security (TRANSEC) and its goal is to engineer the link in a manner

that has low probability of detection and interception. Although anti-jam capability is related to low probability of detection (LPD) and low probability of interception (LPI), the goals to be achieved are different. Anti-jam capability is essential to the operation of the data link. If a link is jammed, either intentionally or unintentionally, the UAV can no longer receive instructions or deliver product data from the payload. The UAV fails to operate. LPD and LPI are more concerned with survivability of an operational UAV. With today's technology, an emitter of heat, light, sound, or radio frequencies can be seen with the use of sensors. If the UAV can be seen, it can be shot down and destroyed. The goal of LPD is to make the UAV less visible to hostile sensors. The operational Archytas design should consider the use of an infrared diffusing outer covering for the UAV to reduce the heat signature from electronic components. All exposed indicator lights on electronic components, usually present for ease of pre-launch testing, should have a blackout capability. Sounding devices such as speakers or alarms should have a silent mode built in. Any radio frequency emitters should be designed to suppress all unwanted and spurious emissions. Intentional emissions should be kept to the lowest power that accomplishes the mission and directional beam antennas, such as a phased array microstrip antenna, should be employed to keep radio frequency emanations from reaching hostile sensors.

> The antenna system has to be designed from the ground up to integrate both physically and operationally with the UAV. The physical structure has to be compact and light weight to fit in the UAV. The control of the antenna system has to be integrated with the autopilot system to ensure that the best antenna, if there is more than one, is always pointed at the ground control station. (Ollevier, June 1991 p. 21)

Consideration of LPI in the design of an operational Archytas goes hand-in-hand with LPD. If the data link cannot be detected, then it is unlikely that the data link will be intercepted and used by hostile force intelligence. Even an encrypted link yields intelligence. The presence of the data link indicates that a UAV is operating in the area. Identification of the UAV, the launching platform type, location, and intention might be deducible, given corroborating intelligence. Even the type of data, whether it is imagery, communications relay or some other, can most likely be determined from an encrypted link.

c. *Modular Data Link Design*

Modular construction of the data link, avionics and the mission payloads will reduce mission changeover time and increase multiple mission capability. Cableless modules that interconnect to the datalink by stacking the payload modules one on top of the other and then on top of the data link would greatly speed up mission changeover time and avoid problems caused by worn cables and connectors.

d. *Automated Take Off and Landing System*

Design for a shipboard automated take-off and landing (ATOL) system is already in progress. Landing an aircraft, especially by remote control, is the most difficult part of the sortie. At sea, the maneuver is even more difficult when attempting to land an aircraft in the wind and on the back of a moving, pitching, and rolling ship. An ATOL system would be integrated with shipboard weather, positioning, and movement instrumentation systems. With this information, the ATOL system would send instructions, through the data link, to the UAV so that the UAV can locate the ship, match its flight attitude to match the surface movements of the ship, then land itself with safe surface contact speed parameters. Unlike normal flight where the ship-to-UAV flight data consists of waypoints and times, a landing attempt would require real time updates at very small UAV movement increments. When the UAV transitions from mission flight to a landing flight mode, the data link could cease the exchange of mission data in favor of landing data. The ATOL system may be an explicit data link operational requirement by FY95.

e. *Multiple UAV Communications*

The engineer for an operational Archytas data link will need to consider that more than one UAV may be operating at the same time in the same area. A method for automatic

clear channel selection of the data link will need to be investigated.

> It is immutable physics that no two entities can occupy the same space at the same time. This fact is every bit as true of electrons as it is of aircraft and automobiles, if not as well recognized. (Takeguchi, 1992, p. 155)

One possible solution is the adaptation of high-speed packet radio or cellular mobile telephone technology in the same manner as the Army's Mobile Subscriber Equipment. Another solution is the use of spread spectrum encoding so that several UAVs can use the same area of the frequency spectrum on a non-interference basis. It is certain that two or more nearby UAVs cannot use the same technique on the same frequency without seriously degrading their communications ability.

B. SUMMARY

The architects and engineers tasked with transforming the Archytas from a proof-of-concept prototype to an production version capable of mission accomplishment in a hostile joint service operation will need to employ a top-down structured approach with a macro view when redesigning any component that interacts or is sensitive to the UAV operating environment. One of the most important interactive components is the data link. The data link controls the UAV and delivers the products of the UAV mission to the users who need it (capabilities). However, the UAV is only a small part of the

overall mission and must perform its part effectively without interference to the rest of the activities being performed (limitations). Between the capabilities and the limitations lie the requirements. The most significant data link requirements have been presented to provide future Archytas project participants a head start with the operational Archytas data link design.

VII. CONCLUSIONS

The data link developed in this thesis for the prototype Archytas was the best solution that could be completed based on funds available at the time. The solution selected was packet radio using an amateur radio protocol and can be improved with very little additional investment in time and money. It was not, however, the best solution, nor will it be compatible with the architecture for an operational Archytas in a shipboard or hostile environment. The best solution for the prototype Archytas was a commercial data and telemetry link specifically designed and manufactured for the application. To develop a data link that would satisfy both the prototype and operational Archytas cannot be done. By the time the prototype has proven the VTOL transitional flight UAV concept, technology will have advanced further and the joint command, control, communications and intelligence architecture in which an operational Archytas must operate will impose greater interoperability requirements.

The data link acquired for the prototype met the criteria for Phases 3 and 4 of the Archytas project. Tests conducted on the data link indicated that the chosen solution met or exceeded the criteria established for its use. The data link works well in spite of its bargain price.

Future research is needed for data link solutions for follow on phases of the prototype Archytas and in preparation for a production version of the Archytas. Areas to be investigated were introduced as enhancements in Chapter V and as operational Archytas design considerations in Chapter VI and include data compression, frequency management, anti-jam techniques, data storage aboard a UAV, link encryption, modes of low probability of detection and interception, and multiple platform control.

APPENDIX A. PARTIAL LIST OF TELEMETRY VENDORS

AACOM, Division of DATUM, Inc., 2430 Stanwell Drive, Concord, California 94520, (415) 827-4784. Designers and manufacturers of command-telemetry-sensor data systems for both unmanned vehicles and flight test telemetry applications.

Aerocon, Inc., 2417 Linden Lane, Silver Spring, Maryland 20910, (301) 495-4800. Manufacturers of RF telemetry modules.

Aydin Vector, P.O. Box 328, Newtown, Pennsylvania 18940, (215) 968-4271. Designers and manufacturers of advanced digital data communications links for unmanned vehicles, drones, aircraft, weapons, land vehicles and shipboard.

Kantronics Inc., 1202 E. 23rd Street, Lawrence, Kansas 66046, (800) 634-3308. Designers and manufacturers of digital communications devices for radio amateurs, industry and government.

Megadata, 35 Orville Drive, Bohemia, New York 11716, (516) 589-6858. Manufacturers of RF modem wireless data communications cards.

Motorola, Wireless Data LAN Division, 1170 Chess Drive, Foster City, California 94404, (415) 286-7051. Manufacturers of R-Net series radio modems and other data radio devices.

NCR Corporation, Integrated Systems Group, Dayton, Ohio 45479, (800) 544-3333. Distributors for the NCR WaveLAN spread spectrum computer networking kits.

Systems Engineering & Management Company (SEMCO), 5950 La Place Court, Suite 200, Carlsbad, California 92008, (619) 438-8280. Designers and manufacturers of telemetry and video transmitters and receivers.

APPENDIX B. COMPLETE LIST OF TNC PARAMETERS

UAV TNC

Asynchronous Port Parameters
(TNC to COMPUTER)

AUTOLF	ON
BREAK	ON
ECHO	ON
FLOW	OFF
FLOWR	OFF
FLOWX	OFF
FLOWTR	OFF
FLOWTX	OFF
INTERFACE	TERMINAL
LEDS	ON
MODE	19200,NONE,8,1
PORT	0
RING	OFF

Control Characters

CANLINE	$18 (CTRL-X)
CANPAC	$19 (CTRL-Y)
COMMAND	$03 (CTRL-C)
DELETE	$08 (CTRL-H)
PASS	$16 (CTRL-V)
REDISP	$12 (CTRL-R)
SENDPAC	$0D (CTRL-M)
START	$11 (CTRL-Q)
STOP	$13 (CTRL-S)
STREAMSW	$7C (¦)
XOFF	$13 (CTRL-S)
XON	$11 (CTRL-Q)

Identification Parameters

BEACON	AFTER 0
BPATH	none
BTEXT	
CTEXT	
CWID	AFTER 0 KEY
HID	OFF
IPATH	none
ITEXT	
KISSADDR	0
MYCALL	KF4LM

Identification (cont)

MYALIAS	none
MYGATE	none
MYPBBS	none
MYREMOTE	KF4LM-5
PBBS	0
PTEXT	
RTEXT	AAAAAA
UNPROTO	TEST

Link Parameters
(TNC to TNC)

AX25LVL	2
Link state is: DISCONNECTED	
CMSG	OFF
CONMODE	TRANSPARENT DEFERRED
CONOK	ON
CR	ON
DISCMODE	COMMAND
DBLDISC	OFF
DIGIPEAT	OFF
LFADD	OFF
MAXFRAME	7
MAXUSERS	1
MODEM	TYPE-B 0,HALF
PACLEN	256
PASSALL	OFF
PBPERSONAL	OFF
RELINK	ON
RETRY	0
USERS	1

Monitor Parameters

CSTAMP	OFF
LIDLIST	none
MONITOR	OFF
MONLIST	none
MONMODE	NONE
MONTYPE	NONE
STREAMCA	OFF
STREAMEV	OFF
TRACE	OFF

Timing Parameters

AXDELAY	0
AXHANG	0
CHECK	0
CMDTIME	1
CPACTIME	ON
DAYTIME	05/MAY/93 08:58:54
DAYSTRING	dd/mmm/yy hh:mm:ss
DWAIT	0
FRACK	1
PACTIME	EVERY 1
PBTIMER	10
PERSIST	255
REMTIMER	2
RESPTIME	1
SLOTTIME	1
TXDELAY	3

GROUND TNC

Asynchronous Port Parameters

(TNC to COMPUTER)

AUTOLF	ON
BREAK	ON
ECHO	ON
FLOW	OFF
FLOWR	OFF
FLOWX	OFF
FLOWTR	OFF
FLOWTX	OFF
INTERFACE	TERMINAL
LEDS	ON
MODE	19200,NONE,8,1
PORT	0
RING	OFF

Control Characters

CANLINE	$18 (CTRL-X)
CANPAC	$19 (CTRL-Y)
COMMAND	$03 (CTRL-C)
DELETE	$08 (CTRL-H)
PASS	$16 (CTRL-V)
REDISP	$12 (CTRL-R)
SENDPAC	$0D (CTRL-M)
START	$11 (CTRL-Q)
STOP	$13 (CTRL-S)
STREAMSW	$7C (¦)
XOFF	$13 (CTRL-S)
XON	$11 (CTRL-Q)

Identification Parameters

BEACON	AFTER 0
BPATH	none
BTEXT	
CTEXT	
CWID	AFTER 0 KEY
HID	OFF
IPATH	none
ITEXT	
KISSADDR	0
MYCALL	KF4LM-1
MYALIAS	none
MYGATE	none
MYPBBS	none
MYREMOTE	none
PBBS	0

Identification (cont)

PTEXT	
RTEXT	
UNPROTO	TEST

Link Parameters

(TNC to TNC)

AX25LVL	2
Link state	is: DISCONNECTED
CMSG	OFF
CONMODE	TRANSPARENT DEFERRED
CONOK	ON
CR	ON
DISCMODE	COMMAND
DBLDISC	OFF
DIGIPEAT	OFF
LFADD	OFF
MAXFRAME	7
MAXUSERS	1
MODEM	TYPE-B 0,HALF
PACLEN	256
PASSALL	OFF
PBPERSONAL	OFF
RELINK	ON
RETRY	0
USERS	1

Monitor Parameters

CSTAMP	OFF
LIDLIST	none
MONITOR	OFF
MONLIST	none
MONMODE	NONE
MONTYPE	NONE
STREAMCA	OFF
STREAMEV	OFF
TRACE	OFF

Timing Parameters

AXDELAY	0
AXHANG	0
CHECK	0
CMDTIME	1
CPACTIME	ON
DAYTIME	07/JAN/90 17:51:17
DAYSTRING	dd/mmm/yy hh:mm:ss
DWAIT	0
FRACK	1
PACTIME	EVERY 1
PBTIMER	10
PERSIST	255
REMTIMER	2
RESPTIME	1
SLOTTIME	1
TXDELAY	3

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